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Department of Agricultural & Applied Economics

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The Dynamics of the U.S. Milk Supply: Implications for Changes in U.S. Dairy Policy

By

Marin Bozic and Brian W. Gould

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Implications for Changes in U.S. Dairy Policy

Marin Bozic
Research Assistant
Department of Agricultural and Applied Economics
University of Wisconsin-Madison

Brian W. Gould
Associate Professor
Department of Agricultural and Applied Economics
University of Wisconsin-Madison

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Introduction

In 2007, there were approximately 80,000 dairy farms with an aggregate herd size of 9.2 million cows and producing 185.6 billion lbs of milk annually. With this milk valued at more than $35.5 billion the dairy sector accounts for 12% of the gross value of US agricultural production (USDA, 2009). The U.S. dairy industry represented by both dairy farms and processing industries are continuing to experience dramatic structural changes that have been accelerating since the early 1970's.

At the farm level there is a continuation of (i) increasing farm size, (ii) an evolution in the technologies being adopted (i.e., rBST, sexed semen, rotational grazing feeding systems), and (iii) a shifting of the location of production away from traditional production areas. For the manufacturing sector over the last 20 years there has been a dramatic increase in R&D efforts devoted to the marketing of new value-added consumer oriented dairy products, the development of new uses of by-products generated from the production of traditional dairy products (e.g., whey-based products, lactose, dairy-based proteins), development of the use of ultra-filtration technologies to improve plant productivity, expansion of the production of products to displace those that have typically been imported (i.e., European style cheeses, casein, milk protein concentrate), and an increase in average processing plant size.

In terms of dairy policy we have witnessed an evolution of dairy policies that are arguable more market oriented than in the past. Finally, the reliance of the U.S. dairy industry on international dairy markets is becoming much more important. This is evidenced by the current depressed domestic milk prices which are in part due to reduced dairy exports. For example in 2008, 11% of U.S. milk production was exported on a solids basis.

A significant characteristic impacting the U.S. dairy sector is the dramatic increase in milk price variability. Figure 1 shows the relationship between the manufacturing grade milk price support level and the monthly Class III (BFP/MW) milk price.[1] Prior to the late 1980's there was very little variability in the manufacturing grade milk price as the price was essentially set by the U.S. manufacturing milk support price. Since the late

[1] The Class III (BFP/MW) price is the minimum price paid for milk using in cheese manufacture under the Federal Milk Marketing Order System.

1980's not only has the Class III price diverged from the manufacturing support price but its variability has dramatically increased.

[Insert Figure 1 About Here]

In terms of its domestic market, total annual dairy product demand is growing in the 2-3% range reflecting a relatively mature market relative to China, Southeast Asia and Latin America (Balyney et al, 2006). This increased demand has been met with a continuously declining number of more productive milk cows. In Figure 2, we show the number of cows in the U.S. dairy herd and average annual production per cow. In 1950 the U.S. dairy herd was composed of 21.9 million cows with an average annual yield of 5,313 pounds. By 1975, the dairy herd had decreased by 48.9% to 11.2 million head with an average annual productivity of 10,358 lbs., a 94.9% yield increase. The 2008 herd size is 42.0% of the 1950 herd while producing 63% more milk. Over 1950-2008, the average yield increased with a compound annual growth rate (CAGR) of 2.3%. In contrast, the size of the U.S. dairy herd was shrinking at the CAGR of -1.4%. Combining these two trends shows that total U.S. production increased at a CAGR of 0.83%. Over the 25 year period, 1950-1975, total U.S. milk production was fairly stable. In contrast, over the last two and a half decades there has been relatively steady annual growth rate with a CAGR of 1.4%.

[Insert Figure 2 About Here]

The above trend of reduced cow numbers and increased yields suggest the trend of increases in farm size (number of cows/farm). Table 1 shows the distribution of U.S. milk production by herd size since 1993. Over this 16 year period, average herd size has more than doubled. The contribution to the total U.S. milk production of the <100 cow size grouping has decreased from 45% to less than 20%. The 200+ herd size group now accounts for more than 70% of production with the 500+ size alone accounting for 54% of U.S. output.

[Insert Table 1 About Here]

One can characterize U.S. dairy policy as having two primary objectives: (i) providing a price support level to establish a minimum level of farm income and (ii) incorporating counter-cyclical price stabilization systems to ensure an orderly supply and marketing of farm milk. These two goals are the main driving forces for the Dairy Product Price Support Program, the Milk Income Loss Contract (MILC) program and the use of classified pricing of milk under the Federal Milk Marketing Order (FMMO) system.[2]

The minimum price of milk used for manufacturing purposes has been supported continuously since passage of the Agricultural Act of 1949. This Act required the Secretary of Agriculture to support prices received by dairy farmers for manufacturing use milk at between 75 percent and 90 percent of parity. The specific parity level within this range was determined by forecasting the adequacy of future milk production in fulfilling market needs. Using assumed yields and manufacturing costs, the support price for manufacturing use milk was converted into a price per pound of cheddar cheese, butter and nonfat dry milk. The CCC stood ready to purchase unlimited quantities of cheddar cheese, butter and nonfat dry milk at these prices to keep the price of manufacturing use milk from falling below the support level. The assumption was that if cheese, butter and nonfat dry milk plants received these prices, then they would be able to pay dairy farmers at least the support price for their milk. In 1973, the minimum support level was raised from 75 percent to 80 percent of parity. The Agricultural and Consumer Protection Act of 1977 continued the minimum support level of 80 percent of parity through April 1, 1981 and required that the support price be adjusted semi-annually (October 1 and April 1) to reflect changes in the Index of Prices Paid by farmer operators. Inflation during the 1970s, and changes farm productivity resulted in the support price increasing from $4.28 per hundredweight on October 1, 1970 to $13.10 per hundredweight on October 1, 1980. Dairy farmers responded by increasing milk production far beyond commercial use. Surplus dairy products purchased by the CCC under the support program approached 10% percent of farm marketings and associated government costs approached $2 billion annually.

This surplus situation resulted in a major change in the support program. The Agriculture and Food Act of 1981 removed the support level from parity. The support price would now be tied to both the level of CCC purchases and associated net

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[2] For a review of the classified pricing of milk under the FMMO system refer to Jesse and Cropp (2008). For a description of the U.S. dairy industry and recent historical dairy policy refer to Blayney et al (2006) and Blayney (2002).

government cost of the program. Under these provisions and subsequent amendments, the support price was gradually lowered. The Food, Agriculture, Conversation and Trade Act of 1990 set a minimum $10.10 per hundredweight support price through 1995. The Federal Agricultural Improvement and Reform Act of 1996 increased the support price to $10.35 per hundredweight for 1996, with subsequent reductions of $0.15 each January 1 to $9.90.

With the passage of the 2008 Food, Conservation and Energy Act of 2008 (2008 Farm Bill) the former *milk* price support program was renamed the *dairy product* price support program.[3] The purchase prices for butter, nonfat dry milk, and cheese are unchanged from the levels existing prior to its passage but they are no longer linked to a specific manufacturing milk price.

Federal Milk Marketing Orders (FMMO's) represent a set of regulations that address the specific nature of milk as a flow commodity, which means that it is produced every day, and must move quickly to market. Fresh milk cannot be stored for a significant length of time without processing, which implies that day-to-day milk supply may not be balanced with demand. Furthermore, in the absence of any of any regulations, milk processing plant owners would have immense power over local dairy farmers. To mitigate the potential adverse effects of this setting, Federal orders have been authorized by the Agricultural Marketing Agreement Act of 1937. Under the current FMMO system, the primary producing areas in the U.S. are divided into 10 regions, and minimum prices to be paid to farmers for their milk are based on the utilization of that milk and the composition of each operator's farm milk. Each dairy farm operator in a particular marketing order obtains the same uniform price for his milk where this milk's value is determined by the valuation of the milk's components such as protein, milkfat, non-fat solids, etc.[4]

In recent years, the market price of manufacturing milk has been much higher than the $9.90 support price. Seeking to provide counter-cyclical support without inducing a new wave of misplaced investments in excess capacity, the Federal

[3] For a review of the dairy sub-title of the 2008 Farm Bill refer to Jesse, Cropp and Gould (2008).
[4] It should be noted that California which produces more than 21% and Idaho that accounts for 6% of the U.S. milk supply are not part of the Federal Milk Marketing Order system and possess their own minimum classified pricing rules.

government enacted a new policy tool starting in December of 2000 and is referred to as the Milk Income Loss Contract (MILC) program. This program provides payments to dairy farm operators to partially reimburse their forgone income when the price of milk used for bottling purposes (Class I) falls below a predefined level.[5] Payments to individual producer are limited by the amount of payment associated with 2.985 million lbs. The current version of the MILC program established via the 2008 Farm Bill modifies the previous version in that: (i) ties the price that triggers an MILC payment directly to feed costs, (ii) raises the pay out percentage to 45% of the difference between the target and actual Class I mover from the previous 32% and (iii) increases the covered milk to 2.985 mil. lbs. from the previous 2.4 million lb. cap.[6]

Study Objectives

There is continuing pressure by various farm groups to attempt to solve the chronic problems in the U.S. dairy industry represented by increased milk price variability, inability to generate positive returns at the farm level, increasing role of dairy exports as an important market for U.S. dairy products, etc. As such it is important for analysts and policy makers obtain an estimate as to how responsive dairy producers are to changing economic and technological conditions. Examples of previous research used to examine supply response in the U.S. dairy sector include LaFrance and deGorter (1985), Chavas and Klemme (1986), Thraen and Hammond (1987), Chavas, Krauss and Jesse (1990), Chavas and Krauss (1990), Yavuz, et al, (1996) and USDA (2007). These analyses are limited in that either they are either fairly dated or they do not account the dynamics that are inherent in the dairy herd expansion/contraction process.

The above overview of the dairy industry points to a changing industry as represented by reduced but larger dairy operations, the changing nature of U.S. dairy policy and pricing, production of new types of dairy products, etc. with much of the adjustments

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[5] Although the MILC trigger price is based on the Class I price mover, the MILC payment is applied to all milk regardless of use and regardless of whether this milk is produced under the FMMO system or a state-based pricing system.

[6] For an overview of the MILC program refer to Jesse, Crop and Gould (2008). A spreadsheet model comparing the previous MILC program to the version established by the 2008 Farm Bill can be found at: *http://future.aae.wisc.edu/collection/software/MILC_simulation_07_08.xls* . A spreadsheet model used to estimate the Feed Cost Adjuster of the MILC can be found at: http://future.aae.wisc.edu/collection/software/milc_cost_adjuster.xls .

have occurred since the above previous analyses were undertaken and may no longer reflect the industries supply characteristics.

The present study will incorporate data encompassing the 1975-2007 period and provide an update of the model original developed by Chavas and Klemme (1986). This study has three main objectives: (i) quantify the current supply structure of the U.S. dairy industry, (ii) gain insight into impacts of technological changes that have occurred over the last 25 years, (iii) based on (i) and (ii), generate forecasts of long-run milk supply response to price changes and possible future technological advancements.

Description of an Econometric Model of U.S. Milk Supply

The econometric model adopted here has the general structure of the national model of U.S. milk supply used by the Dairy Division of the Agricultural Marketing Service of USDA when examining the impacts of changes in FMMO pricing regulations, enactment of major dairy policy changes, etc. (USDA, 2007). That is, similar to USDA (2007) we start by assuming that total U.S. milk production (MILK) is the product of the number of milk cows in the U.S. dairy herd (COW) and the average yield per cow (YLD). Given that our model is annual in nature we have:

$$MILK_t = COW_t \times YLD_t \qquad (1)$$

where t represents the t^{th} year.

Following Chavas, and Klemme (1990) and Chavas and Krauss (1990) we extend the USDA specification by explicitly accounting for the dynamics of the U.S. dairy herd size as it is impacted by both producer culling and replacement decisions as well as the biological characteristics of dairy herd replacements.[7] The understanding of biological and economic decisions governing the dairy herd dynamics can best be exploited by separately examining the determinants of herd size (COW) and yield (YLD) via the use of two separate stochastic regression models.

The herd size specification used here is based on the underlying dairy cow biology. The reproductive cycle of a typical dairy cow is 14 months where 9 months is the length of pregnancy and 5 months is the current industry average period between freshening

[7] For a more complete description of the underlying biological and economic models, refer to Chavas and Klemme (1986)

(giving birth to a calf) and start of the next pregnancy. Cows produce milk from the initial birth to approximately two months prior to next birth at which time they are removed from the milking herd to rest before the next delivery. Newborn calves take approximately 9 months to reach the weight of 500 pounds which USDA considers as replacement heifers given they have not yet calved. Heifers are impregnated at 15 months of age and thus give birth when they are approximately 2 years old.

For our current model, a replacement heifer in period *t* (HEF_t) is a female calf at least one year of age at the beginning of the year and is expected to enter the herd before the end of the year. Upon first calving, a replacement heifer is then considered to be a dairy cow and part of the dairy herd.

While the maximum biological age for a cow is about 20 years, intensive milking and frequent calving make cows susceptible to various diseases. While those health problems are mostly treatable, they tend to make the economic life of the cow much shorter than the maximum possible physical age. When culled from the herd a dairy cow is typically sold for slaughter. The age at which a cow is removed from the herd depends on a number of factors including expected future productivity, current and expected milk versus slaughter prices, current/expected feed costs, improved yield potential of cow replacements and current/expected replacement heifer costs.

We can describe the U.S. dairy here not only by its size but also with respect to the distribution of cows across different age classes since a particular cow can produce milk over a number of yearly cycles. Both these characteristics are determined primarily by timing of culling and cow replacement. For the present study we assume that heifers enter the herd when they are 2 years old, and that maximum productive lifetime of a dairy cow is 9 years which implies a maximum economic life of 11 years. During the t^{th} year a particular dairy cow belongs to a particular age class (AGE_i) where i = 1,…,9. In other words, $AGE_{t,i}$ represents number of years a cow has been in the milking herd in year t.

We assume that each year a dairy farm operator makes a decision as to how many cows within each of the 9 productive age classes will be kept in the herd for another year. We represent the decisions by survival rates, S_{ti} which is defined as the probability that in year *t* a cow in the i^{th} productive age class will survive (i.e. stay in the herd) one more year. Using the logistic functional form, we specify the survival rate as:

$$S_{ti} = \frac{1}{1+e^{Z_{ti}\beta}}, \quad (i=1,...,9) \quad (t=1,...,T) \tag{2}$$

Where Z_{ti} is a vector of explanatory variables reflecting the state of technology, economic conditions, age class at the time of selection decision and β is a vector of coefficients to be estimated.

The number of cows in i^{th} productive age class is determined by the product of the number of replacement heifers *i* years ago and retention rate, R_{ti} which is the product of survival rates in the past *i* selection decisions and can be represented via the following:

$$R_{ti} = \prod_{j=1}^{i} S_{t-j,i-j} \tag{3}$$

where j is an index used to access previous years and age class survival rates. For example, suppose we want to calculate the retention rate for cows who are in the 3^{rd} age class in 1990. Via (3) we have the following: $R_{1990,3} = S_{1987,0} \times S_{1988,1} \times S_{1989,2}$. Note that $S_{t,0}$ represents the survival rate of replacement heifers that have not yet entered the milking herd.

Total herd size (COW) can be represented as the sum of cows in each of the nine productive age classes. We can thus specify the stochastic herd size equation via the following where we recognize the relationship between heifers in previous years and the current herd productive age class structure:

$$COW_t = \sum_{i=1}^{9} COW_{ti} + e_t = \left(\sum_{i=1}^{9} HEF_{t\text{-}i} \times R_{ti} \right) + e_t \tag{4}$$

where HEF_{t-i} are the number of heifers i years prior to the t_{th} year and e_t is a stochastic error term. We can incorporate the definition of age-specific retention rates from (3) and modify (4) to the following:

$$COW_t = \left(\sum_{i=1}^{9} HEF_{t-i} \left[\prod_{j=1}^{i} \left(\frac{1}{1+e^{Z_{t\text{-}j,i\text{-}j+1}\beta}} \right) \right] \right) + e_t \tag{5}$$

Note that with (5) we can predict not only the number of cows in the dairy herd but the distribution of cows across productive age class.

The complement to the survival rate is the age-specific culling rate k_{ti} which is defined as the proportion of the i^{th} productive age class removed from the herd in the t^{th} year.

$$k_{ti} = 1 - S_{t,i} \tag{6}$$

As stated previously, replacement decisions describe the selection of female calves to become replacement heifers. Underpinning the modeling of the replacement decision is a representation of the probability of a cow successfully calving and that calve surviving until year 1 of age (Γ). We represent this probability via the following logistic relationship

$$\Gamma_t = \frac{1}{1 + e^{W_t \gamma}} \tag{7}$$

where W represents a vector of exogenous variables hypothesized to impact calving/survival probability. This implies the number of heifers available to the dairy herd in the t^{th} period can be represented via the following:

$$HEF_t = 0.5\left\{\left(COW_{t-2} + HEF_{t-2}\right) \times \frac{1}{1 + e^{W_t \gamma}}\right\} + \varsigma_t \tag{8}$$

where ς is a stochastic error term. Note that in the above we use the value 0.5 given that for a majority of our study period, the use of sexed seaman was not technologically possible.[8] Thus we assume that half of newborn calves will be male animals and cannot be used as a cow replacement. In the above we depart from Chavas and Klemme (1986) and adopt the specification of Schmitz (1997) where we model the pool of fertile animals that can produce offspring to include not just dairy cows in the period *t-2*, but also replacement heifers at that time, thus the inclusion of HEF_{t-2} in (8).

The estimation of (5) and (8) provides the method use to estimate the number of cows in the dairy herd. The additional information needed to generate an estimate of U.S. milk production is an estimate of average annual per cow productivity. Following USDA (2007), Chavas, Jesse and Krauss (1990) and Chavas and Klemme (1986) we represent milk yield as stochastic where the impact of a number of exogenous variables on yield is captured via the following simple linear form.

$$YLD_t = X_t \alpha + \nu_t \tag{9}$$

where X is a vector of exogenous variables impacting milk yield and ν is a stochastic error term.

[8] For a discussion of the sexed semen technology, refer to Overton (2007).

Given the above, our econometric model is represented by stochastic regressions contained in (5), (8) and (9). We use the estimation strategy of Chavas and Klemme (1986) where each equation is estimated via single equation least squares. Equations (5) and (8) given their nonlinear (in parameters) structure are estimated using single equation non-linear least squares procedures. Given the above nonlinear specifications the marginal effects of changes in the exogenous variables will have the opposite sign of the estimated model coefficients.

Description of Data Used in the Analysis

The above econometric model is estimated using annual data that encompasses the 1975 – 2007 period. Given the lags involved in the herd size equation data encompassing the 1966 – 1974 period were also used in estimation. Table 2 provides a representation of the categories of exogenous variables used in the three stochastic equations. In each equation there are three types of exogenous variables: (i) those that capture the state of technology and herd structure; (ii) variables used to describe the economic environment; and (iii) a set of dummy variables that identify time periods during which unique government policies impacting the dairy industry were in effect. Table 3 provides the definitions of the variables that comprise the above categories.

[Insert Table 2 About Here]

[Insert Table 3 About Here]

Technological Progress Variables

The level of technology is represented explicitly in the heifer equation (8) by a simple trend variable. The non-linear functional form used in (8) allows for the impact of technology to change over time. For example due to improved technology, attempts to fertilize cows may be more successful, calf death rates can be reduced, and more calves selected to be grown into replacement heifers actually completing the process without severe health problems that would induce involuntary culling.

In the yield equation (9), we assume the trend variable primarily reflects genetic improvements of dairy cows. Indeed, we will see that this trend variable is the major determinant of changes in per cow productivity.

Herd structure is incorporated in the herd size equation by two variables. First, as noted above, inclusion of the productive age class variables (AGE_j) allows survival rates to differ across the 9 productive age classes. Secondly we include as an exogenous variable lagged replacement ratio, REPLACE, which is defined as the ratio of replacement heifers to dairy cows. A higher replacement ratio implies that more heifers are ready to enter the herd, and consequently, more of the older, less productive cows, can be removed from the herd without reducing herd size. We assume the effect of higher replacement ratio will be different for different productive age classes. As such we interact the AGE and associated replacement ratio, $\frac{HEF_{t-j}}{COW_{t-j}}\left(AGE_j - 3\right)$, variables. Following Chavas and Klemme (1986) we assume that higher heifer availability does not influence culling decision of cows that entered the herd in previous period. This assumption is reflected in our subtracting 3 years from the AGE variable.

Technological progress is also reflected in the use of the 0.5 multiplier in the heifer equation. That number reflects the expected ratio of female to male calves immediately after calving, before any culling decision is made. With further technological progress and decline in the price of sexed-semen services, wider adoption of that technology is likely to push this parameter in the range of 85%-90% (Overton, 2007). While we fix this parameter when estimating the model, by increasing its magnitude in some simulated scenarios we are able to make a first pass at investigating the impact of sexed-semen adoption on the price responsiveness of the U.S. milk supply.

Economic Environment

Given that we focus only on the supply side of the dairy industry we include three set of prices that characterize the dairy sector economic environment: All-milk price (MP_t), feed price (FP_t) and slaughter cow price (SP_t). All prices are placed in real terms by dividing by the CPI. In contrast to Chavas and Klemme (1986) who use milk/feed and slaughter/feed ratios as principal economic variables we allow for the data to determine the relative milk-feed and slaughter-feed price impacts. The milk, feed and cow slaughter prices used in the model are all expressed in 2007 dollars. For milk price we use the published U.S. all milk price per cwt published by the USDA. Starting in December 2001 the Milk Income Loss Contract (MILC) program was adopted as a

Federal dairy policy. The MILC program was included in the Farm Security and Rural Investment Act of 2002 and is a type of target price/deficiency payment program that makes a direct payment to dairy producers when milk prices fall below a specified trigger level. This program includes a payment feature that limits the amount of a producer's annual milk sales eligible for MILC payments. The 2002 farm bill authorized the MILC program through September 30, 2005. Subsequently, the MILC program has been reauthorized through August 31, 2007 under the Agricultural Reconciliation Act of 2005 and the 2008 Farm Bill.[9] We account for the MILC program by calculating average annual per cwt payment and adding this value to the U.S. All-Milk price for years 2001-2008.

We define feed price (FP) in a manner similar to that of USDA (2007) and by Chavas, Klemme and Krauss (1990) who use the costs of a 16% protein dairy feed ration to represent feed price. Based on USDA's formulation, this ration is composed of 41% corn, 8% soybeans and 51% dry alfalfa hay. This is the assumed ration used in the feed cost adjuster to determine the level of deficiency payment under the current MILC program. For slaughter cow price (SP) we use the Omaha and Sioux Falls boning-utility grade cow slaughter price.

We assume that culling decisions are made in such fashion to equalize the present value of expected future earnings from milk sales with the current salvage value as represented by the slaughter cow price. We implicitly assume adaptive expectations where future prices are expected to be equal to last observed price. In the cow equation (eq. 5), prices are lagged up to nine periods. Given the assumed form of price expectations, proper interpretation of these lags is that past culling decisions, which are irreversible and depend only on past expectations, still influence the herd size and structure by determining the retention rate of each productive age class at the beginning of the current culling decision period.

Changes in the economic environment will influence each productive age class differently. When production is more profitable, the herd manager might decide to replace more of the older, less productive cows. The opposite holds as well, when prices

[9] For a description of the current version of the MILC program, refer to Jesse, Cropp and Gould (2008) and to the following URL: http://future.aae.wisc.edu/milc.html .

make for less lucrative production, it will not be profit-maximizing to invest in more productive, but expensive, replacement heifers, and that might be reflected in higher retention rates of older cows.[10] To capture the differentiated effect of price changes upon each productive age class, we use price-age interaction variables (i.e.MP_{t-j} x AGE_j) in the herd size equation (5).

To understand how prices influence the number of replacement heifers, recall that it takes 1 year for a female calve to grow into replacement heifer ready to freshen and that a cow is pregnant for 9 months before giving birth to calf that is to become a replacement heifer. The relevant pool of dairy animals that could give birth to calves that will have grown to replacement heifers by period *t* is the number of cows and replacement heifers in period *t-3*. The number of replacement heifers available today is first determined by how many of these cows and replacement heifers are to be impregnated in period *t-3* and how many animals are culled. Culling decisions, given the assumed form of expectations, depend on prices observed in period *t-3.* A second factor impacting the number of replacement heifers available today is the share of female calves that are selected to be grown into replacement heifers. To capture the effect economics have on this decision we include prices in period *t-1*.

While the yield equation with its simple linear structure may seem the most straightforward to interpret the effect of our exogenous variables, it is in fact the case that impact of prices on yield are theoretically the most challenging to understand as there are possibly two opposing effects on yield that occur with any price change. One of the most important day-to-day decisions a dairy farm operator must make is the composition of the feed ration. With increases in milk prices or decreases in feed costs, the producer would like to increase the feed ration to capture this additional income. In addition, these relative price changes impact the desired herd size of many producers. That is, dairy farm operators with relatively high milk prices would like to enlarge their herds and those farm operators who intended to exit the industry may decide to postpone retirement. Should there be scarcity of replacement heifers at that point, farmers will increase the

[10] It should be noted that that we model the U.S. dairy herd as one representative herd in a competitive market. For this specification we cannot account for the importation of dairy replacement heifers. Thus we assume that heifers are not traded and can only be grown. This assumption justifies the exclusion of live replacement heifer price as one of the economic variables in heifer equation.

retention rate of older cows, not because they would seek to increase their milk output, but to increase the future pool of heifers. Retaining more of older cows and thus increasing overall herd size, however, will increase in the short run the share of less productive animals in the herd, and will work to decrease yield, even while increasing milk production. This implies that there can be no clear theoretical prediction as to the expected impact of changes in economic environment to immediate changes in yield. The two effects may cancel each other out, or either can dominate the other. Within one period after the change has occurred, we would expect the short-run adjustments to be completed which is why we include milk and feed prices in period *t-1* as explanatory variables. We further try to capture the adjustment dynamics in the yield equation by including the lagged yield as one of the explanatory variables.

Policy Environment

A third category of explanatory variables used to explain herd size and heifer availability are a set of dichotomous variables used to capture the impact of changes in government policies. There are three federal programs that we include in our model. The variable *Dum84* captures the effect of Milk Diversion Program enacted from January 1984 – March 1985. Under this program participating producers were eligible for payments of $10 per hundredweight on the difference between their "base period" sales and actual sales provided their actual sales were between 5% and 30% below base (Lee and Boisvert, 1985; Boynton and Novakovic, 1984). This policy was part of the comprehensive package of measures that sought to decrease the chronic surplus of milk production. Although program was in effect for 14 months, since it is expensive to keep idle cows on feed, we assume that culling and replacement decisions in that year where influenced by this policy, with cows being more likely to get culled, and female calves more likely to be grown to replacement heifers to substitute for the culled cows in the subsequent years after the end of policy-based incentives.

The Milk Diversion Program was complemented by a much more thorough Dairy Herd Termination Program active from September 1986 to the end of 1987, and accounted for by variable *Dum86.* Under DTP, participating farmers were paid to slaughter or export their entire dairy herds. In addition, participants agreed to remove themselves and their facilities from dairy production for at least 5 years.

Identification of our Dependent Variables

As noted above there are four dependent variables in our model. Dairy herd size, COW_t is composed of all dairy cows as of the January 1st USDA inventory estimate of the number of milking cows. Annual per cow milk yield (YLD_t), the 2nd dependent variable, is obtained from the National Agricultural Statistical Service. The number of replacement heifers (HEF_t) was obtained by multiplying USDA's January 1st Cattle inventory data for "500lbs + dairy heifers" by the factor 0.75 . Heifer calves that are between 8 and 12 months of age on January 1 when survey is done, weigh between 500 and 800 lbs, and are included in the USDA estimate as replacement heifers. Nevertheless, those animals are too young to give birth in the current period. With pregnancy duration of 9 months, a heifer must be impregnated no later than the end of March to freshen before the end of the period. Since heifers are inseminated at 15 months of age, only those animals that are at least 1 year old should be treated as replacement heifers according to definition we employ for the purposes of this model. If we assume that there are 3 times more heifers of age 12-24 months then heifers of age 8-12 months our correction coefficient *(0.75)* is well justified.

One might make case for different specification of this correction procedure, using inventory accounting to arrive at numbers of heifers that have actually entered the herd in the t^{th} period. Schmitz (1997) follows such approach in his research on beef industry, and calculates beef replacement heifers as sum of annual beef herd size change and number of beef cows that have been slaughtered or have died. Employing a similar procedure to dairy sector will not help reduce noise in heifers data, as the estimated number of dairy cows slaughtered are much less reliable than estimates applied to beef cattle due to, among other things, biased accounting procedures in those slaughterhouse which primarily service the beef industry.

Estimation of an Empirical Model of U.S. Milk Supply

The estimation period for the model spans the 33 year period 1975 - 2007.[11] We estimate each of the stochastic equations separately using least squares methods. The yield

[11] In 1970 USDA changed the categorization of dairy cattle from a age-based to weight-based system. Since that change artificially reduced the published number of dairy cows by 2 million from 1969 to 1970,

equation is estimated by OLS while the equations for herd size (eq 5) and heifers (eq 8) are estimated via nonlinear least squares using the Gauss-Newton (GN) algorithm. Given the degree of nonlinearity of these last two equations the sum of squared errors (SSE) function are likely not globally convex over the parameter space. This implies that there are potentially numerous local SSE minima. To insure that the algorithm converges to a local minimum, we estimated eq. (5) and (8) 4,000 times, each time using a different randomly drawn vector of starting values for the coefficients. From the vector of solutions, our estimate of the global minimum is then identified by a simple ranking of empirical SSE values.

Given the nonlinear nature of eq.. (5) and (8) one must rely on asymptotic properties of the estimated parameters to determine their distributional characteristics. In small samples such as the one used here and when the model is highly non-linear, applicability of large sample theory may be inappropriate and any estimate of asymptotic standard errors of the coefficients must be taken with caution. One clear indicator that large sample theory performs poorly for some model would be that bootstrap estimates of confidence intervals of coefficients are much different than confidence intervals based on asymptotic theory.

To determine if our model possesses such discrepancy, we use a residuals-based bootstrapping procedure to simulate the data generating process and obtain alternative estimates of parameter standard errors. The bootstrapping procedure simulates alternative samples assuming the estimated coefficients are the true unknown parameter values. Alternative dependent variable vectors are generated by using random draws from joint empirical distribution of estimated residuals. Specifically, the following bootstrapping procedure is used:

(1) Estimate the three equations stochastic equations using least squares procedures. From these regressions evaluate equation specific errors and concatenate these error vectors to form (T x 3) error matrix.
(2) Use the estimated coefficients to predict the number of heifers, cows and yield in 1975, which is the first estimation year. Randomly draw a row from the above matrix of estimation residuals and add the residuals to the

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we use USDA "January average" series for dairy cows for all years prior to 1970, which corrects for the inventory definition change. Unfortunately, there is no published data that corrects for change in their heifer definition. Although data for all dependent and explanatory variables are available from as early as 1951, we were not able to estimate the model prior to 1975.

associated predicted values of the dependent variables to generate simulated values for our dependent variables: heifers, cows and yield.

(3) Obtain simulated value for heifers, cows and yield in 1976:
   a. Predict number of cows in 1976, using simulated cows and heifers in 1975 as explanatory variables in the herd size equation. For all other explanatory variables (prices, technology, policy dummies) use actual data for 1976. In similar manner predict 1976 heifers and yield.
   b. Add randomly chosen residuals to obtain simulated values for the three dependent variables as was done in (2).

(4) Repeat step (3), for the remainder of the sample, always using previously obtained simulated values for previous years whenever lagged dependent variables or their ratios enter as explanatory variables in any equation.

(5) Steps (1)-(4) create one sample from the joint distribution of heifers and cows, given assumed data generating process governing herd dynamics. Re-estimate the cows, heifers and yield equation using the simulated sample, and store the results of the estimation.

(6) Repeat steps (1)-(5) 4,000 times.

We use the percentile-t method to obtain bootstrap confidence intervals of parameter estimates and compare them with asymptotic confidence intervals based on the original parameter information matrix (Hansen, 2008).

Overview of Estimation Results

Table 4 is used to present estimated coefficients and bootstrapped standard errors for the heifer and herd size equations. Remember in the heifer equation (eq. 10.1) the explanatory variables are used within a "survival rate" function which represents the probability of a heifer being freshened and allowed to enter the milking herd. With the exponential function in the denominator, the marginal effect of a change in a regressor on the survival probability will have the opposite sign as the estimated coefficient. Given its definition, the marginal effect on the heifer "culling rate" which is one minus the heifer survival rate will have the same sign as the estimated coefficient. In terms of interpreting the herd size equation, we need to remember that the number of cows of a particular age in the herd is the product of the number of heifers in previous years times the combined probability of surviving to the current time period. Similar to the heifer equation, these survival probabilities are specified as being logistic. Thus the *culling rate* marginal impacts of a change in an exogenous variable will have the same sign as the estimated coefficient in the cow survival function.

Given the above, we would thus expect to see the milk price coefficient in equations [10.1] and [10.2] to be negative as we anticipate the two culling rates to be negatively related to milk price. The higher the milk price, the greater the profitability associated with milk production and a reduced incentive for culling cows, ceteris paribus. Conversely, our initial hypotheses are that higher feed and slaughter prices will have a positive impact on the culling rate for heifers and milk cows.

As reviewed above, the Milk Diversion and Whole Herd Buyout dairy policies had as their primary objective the reduction in the U.S. herd size. We would therefore expect a positive effect of these policies on the culling rate and therefore expect positive coefficients on the associated policy-related dummy variables in the herd size equation. Even though it decreased the number of dairy cows, the Milk Diversion Program did not have a requirement that producers permanently leave the dairy industry. As such, we anticipate with a reduction in the milking herd there would be an subsequent increase in the demand for replacement heifers. Thus we anticipate the sign of the estimated coefficient associated with the variable *Dum84* to be negative in the heifer equation.

Estimating the above three equations by least squares, we obtain a high degree of in-sample prediction accuracy. The cow equation has a maximum absolute prediction error of 2.2%, 3.6% in the heifer equation and 2.5% in the yield equation. In Figure 3 we provide a representation of the actual, static prediction and dynamic simulations of the number of heifers and size of the U.S. dairy herd. In addition we provide a 95% confidence interval of these variables based on our bootstrapped results.

In the heifer equation, all estimated coefficients were found to be statistical significant at the 5% confidence level. In the herd size equation, the milk price and interaction of the milk price and cow age were found not to be individually significant.[12] To determine if the combined effect of the price, we test for joint significance of coefficients for average and age-specific impacts of milk price. Results of individual Wald tests show that the combined average and age-specific impacts of prices of milk and feed are highly significant. We did not find any significance for cow slaughter price. This last result is not surprising given that over the last 25 years, yield per cow has doubled. This implies

[12] A comparison of the bootstrapped and Information Matrix based parameter standard errors showed little difference in the interpretation of individual coefficient statistical significance.

that the salvage value of cow represents a much smaller fraction of present discounted value of future earnings from the cow. Consequently, culling decisions were found to be influenced by milk price to a larger degree than the cull cow price.

Since all parameters in the heifer and cows equation are in the exponent of the logistic function, it is not straightforward to determine the magnitude of price change impacts on short run culling rates. To address this issue, in Table 5 we present predicted marginal impact of price changes on culling rates of each cow productive age class in 2007. Cull rates are given in the second column, and the rest of the table shows changes in the culling rates induced by 10% change in prices. For example, culling rate for cows in the second productive age class, which corresponds to 4 years of age, is 17.3%. This implies that of the cows that survived the first year in the herd, 17.3% will be culled in 2007. Increase in milk price by 10% over average milk price for 2007 (19.13 USD/cwt) would decrease the culling rate by 0.9% to 16.4%. Both Wald test and tests for significance of marginal impacts of prices on culling rates indicate that our model shows statistically significant impact of milk price on cow herd dynamics.

Evaluation of Long-Run Price Effects on U.S. Milk Supply

To evaluate the long-run (10 year) impacts of price changes on the U.S. dairy herd we address the following question: *If real prices remain constant over the next ten years, what will be the impacts on U.S. milk production?* To address this question, we evaluate 10 year production profiles under the following 3 price scenarios:

(i) *Scenario 1*: The All Milk, Slaughter and 16% Dairy Feed Prices remain at their average 2005-2006 levels

(ii) *Scenario 2*: Prices stay at their 2007 levels. It should be noted that 2007 was a relatively good year for dairy industry in spite of high grain prices. The U.S. All-Milk price averaged $19.14/cwt, the average corn grain price was $3.39/bu and the average soybean price was $7.74/bu.

(iii) *Scenario 3*: To investigate the long-run impact of extremely high feed costs under this scenario we assume that prices over the next ten years stay as following: Corn – $5.50/bu, soybeans – $12.00/bu, Alfalfa Hay – $165.00/ton.

Under all scenarios cow productivity improvements are assumed to follow the structure represented by the estimated yield equation (10.3) shown in Table 4. Figure 4 is used to portray milk production under the above three scenarios over the 2008-2017 period. In addition we have plotted the bootstrapped confidence interval for Scenario 1. It is not surprising that the optimistic milk price environment represented by Scenario II generates a large increase in milk production relative to the base case of Scenario I. Starting with 2010, the estimated production under Scenario II is above the upper level of the 95% confidence interval of estimated production under Scenario I. By 2017, the estimated production under Scenario II is 4.2% above the upper confidence level. Similarly, the high feed cost scenario, Scenario III, generates substantially lower milk production levels starting with production in 2010. In 2010, milk production under Scenario III is 0.4% less than the lower confidence interval boundary obtained for milk production under Scenario I. This relative decline increases to -19.4% by 2017.

Given the above results we evaluate long-run herd size and milk production elasticities to milk, feed and slaughter price changes. We evaluate these elasticities via the following procedure:

i) Choose the starting year.
ii) To obtain point estimates of the elasticities we use the estimated parameters obtained from the regression models
iii) To obtain the confidence intervals of these elasticities we randomly draw from the bootstrapped parameter estimates along with the estimated residual matrix. Thus we account for uncertainty in our estimated coefficients and the presence of information uncertainty.
iv) Set prices for the next 10 years to be the same as in the starting year. This is referred to as the *base scenario*. The 10-year period that begins with starting year is referred to as the *simulation period*.
v) Undertake dynamic simulations of the number of cows, heifers and total milk production for each year of the simulation period.
vi) Identify exogenous variable for which elasticities are to be calculated (e.g., all-milk price, slaughter cow price, cost of a 16% dairy ratio).
vii) Increase the above variable in the initial year to be 10% higher than observed. Keep other prices unchanged.
viii) Set prices for the next 10 years to be the same as in starting year but at the higher level, i.e. alternative scenario.
ix) Simulate the number of cows, heifers and the total milk production under the alternative scenario in each year of simulation period, using the same matrix of forecast errors as in base scenario simulations.
x) For each year in the simulation period, calculate the arc elasticity of the number of cows, number of heifers and U.S. milk production under the alternative and base scenarios.
xi) Calculate elasticity confidence intervals by repeating (i) – (x) 1,000 times

In Table 6 we provide point estimates of the milk and feed price elasticities along with the limits that define the 2.5 (Low) and 97.5 (High) percentiles of the empirical distribution of bootstrapped long-run elasticities average over the 1978-1982 and 2003-2007 periods.

There are several patterns to obtain from Table 6. First, regardless of the starting year, it was not surprising that the long-run elasticities are much higher than short- and intermediate-run elasticities given the dynamics of the dairy herd adjustment process. Second, by comparing elasticities across different starting periods, we see that price-responsiveness of dairy industry has not increased over the last 25 years. One might expect that with better genetics, improved heifer management and larger farms the industry would be likely to react to prices more quickly than smaller dairy operations.

To investigate this issue further, we plot the 10-year herd-size elasticities, calculated for each year in the sample, in Figure 5. This figure is used to display the 10 year elasticities depending on year of price change initiation as well as the 5% confidence interval of these elasticities. While the mean of the elasticity shows a clear downward trend, bootstrapped confidence intervals are large enough that the point estimate for the 10-year elasticity in 2007 falls within confidence interval for elasticity calculated in 1980, and vice versa.

We would like to formally test whether price-responsiveness has changed over the 1980 – 2007 period. We do this by comparing the empirical distribution of the 10-year elasticities for herd size, number of heifers and total milk production for 1980 and 2007 for both the all-milk and 16% dairy feed prices. To undertake this test we simulate the distribution of differences between 10-year elasticities for 1980 and 2007. If null hypothesis is correct, than the distribution of differences should be roughly centered around zero. We reject the null hypothesis if number of simulations in which 2007 is less price-responsive than 1980 is less than 5% of total number of bootstrap simulations. Using this test procedure, we can conclude that 10-year elasticities of heifers, cows and total milk production with respect to milk price were higher in 1980 than in 2007. As for the feed price, we can only conclude that elasticity of number of heifers to feed price was higher in 1980, while results are inconclusive for number of cows and total milk production.

The conclusion that long-run elasticities have declined is unexpected. While we only observe annual inventory data for cows, the structure of our model allows us to predict the herd structure by age at any year in the sample. In Figure 6 we plot the distribution of herd by cow age and retention rates for each age class for two time periods, 1998-1982 and 2003-2007. The implication from this figure is that while cow retention rates for cows age 3-5 (first three lactations) have remained the same over these two time periods older cows are significantly less likely to be kept in herd. For dairy operations, the major adjustment to changes in the economic environment is accomplished via herd culling and replacement activities. When dairy farm operators experience positive changes in the economic environment and they desire to expand their herd, they can (i) keep current milking cows longer in the herd while maintaining previous replacement rates or (ii) increase the share of female calves that are grown into replacement heifers and ultimately added to the herd. The younger the herd, the higher replacement ratio needed to keep the herd size unchanged.

We argue that the reduction in long-run price responsiveness is the result of increases in involuntary cull rates that makes it harder for dairy farm operators to increase the retention rate of cows in the process of adjustment to favorable changes in economic environment. Hadley (2006) reports that in DHI herds health culls, i.e. culls induced by health problems of a cow, constitute 79.5% of all culls. If the share of health culls in all culls has increased over time that would imply that culls are starting to be less of an economic decision, and are increasingly a consequence of biological constraints. Furthermore, health culls are greater constraint on expansion, then on reducing the herd, for farmer can always decide to increase the cull rate up to 100%, but health culls represent the lower bound beyond which culls cannot be easily reduced.

Conclusions

The econometric analysis contained in this study is an update of Chavas and Klemme (1986). We felt that an update was required given the significant structural and policy changes that have occurred in the U.S. dairy industry since their manuscript was first published. We find the model performs very will with respect to in-sample simulations.

Our results, as represented by various price elasticities, differ significantly from those obtained from the original model application.

Several conclusions emerge from our study. First, given the large difference between short-run and long-run responses of production to price changes, policy makers are cautioned not to discard or vindicate any policy changes based solely on how industry reacts after one or two years after the changes are introduced. What may in the short-run seem like a minor impact that does not disturb market equilibrium can indeed lead to large production surpluses after more time has passed and dairy herd size has had adequate time to adjust to the new policy environment.

Second, a focus on yield in genetic selection, while rational from the perspective of a single producer, may have unfavorable side-effects on an industry level. Reduction in long-run price responsiveness of supply will occur if the length of economic life of a cow is reduced implying that more replacement heifers are required to maintain a stable herd size.

Finally, wide adoption of sexed semen in replacement heifer breeding is likely to play a major role in how the industry evolves. We have undertaken some preliminary analyses of the impact of increasing the proportion of female dairy calves by adjusting the 0.5 constant in the heifer equation. Our initial analyses suggest that the impact on the industry supply curve will be to increase the All-Milk price responsiveness.

The obvious shortcoming of this model is that it assumes that market prices are predetermined. We are currently extending this model to incorporate its dynamic framework into a partial equilibrium model of the dairy sector similar to USDA (2007). The main advantage of such a model in that not only are we able to evaluate the impacts of specific policy changes on the level of milk production but we will be able to examine the policy and technological change impacts on equilibrium market prices. We will then use this model to examine the impact of: changes in MILC program rules (i.e., higher payment rate, higher covered milk production limits, changes in feed cost adjuster); implementation of alternative supply management programs (i.e., CWT, the Holstein Association plan, the Milk Producers Council plan, and a USDA Whole Herd Buyout program); and the impacts of the adoption of alternative technologies (i.e., sexed semen, reduced use of rBST, and increased use of rotational grazing)

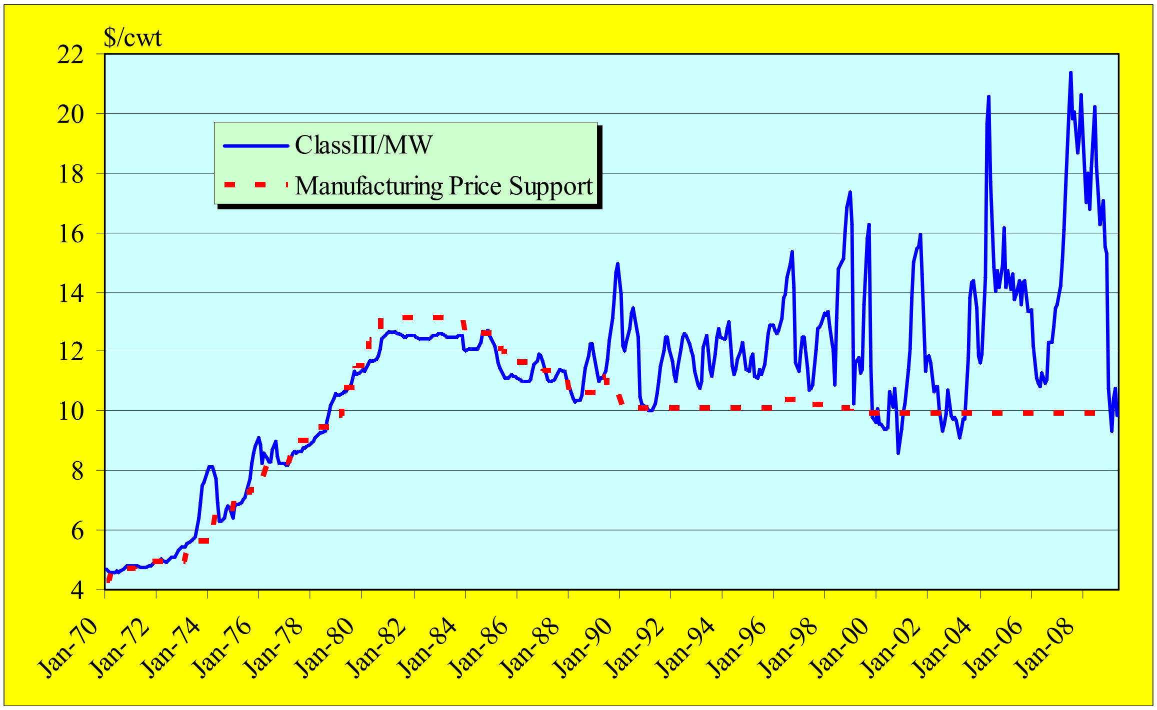
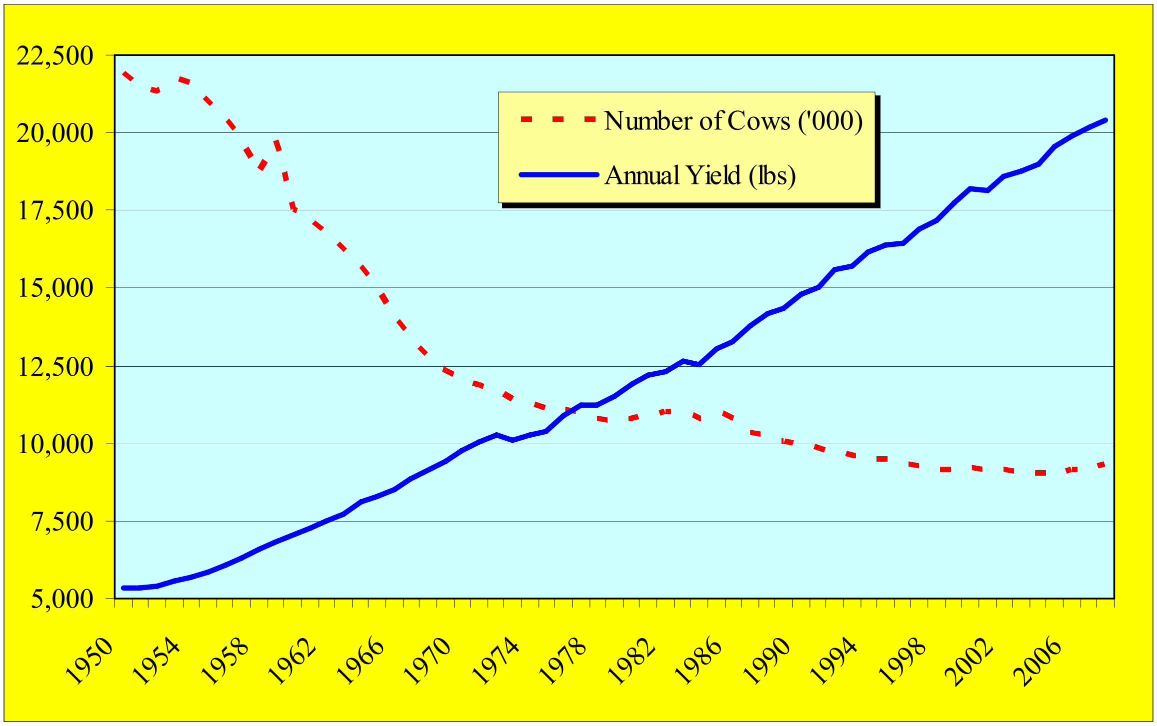


Figure 1. Relationship Between Class III/M-W and Manufacturing Support Price



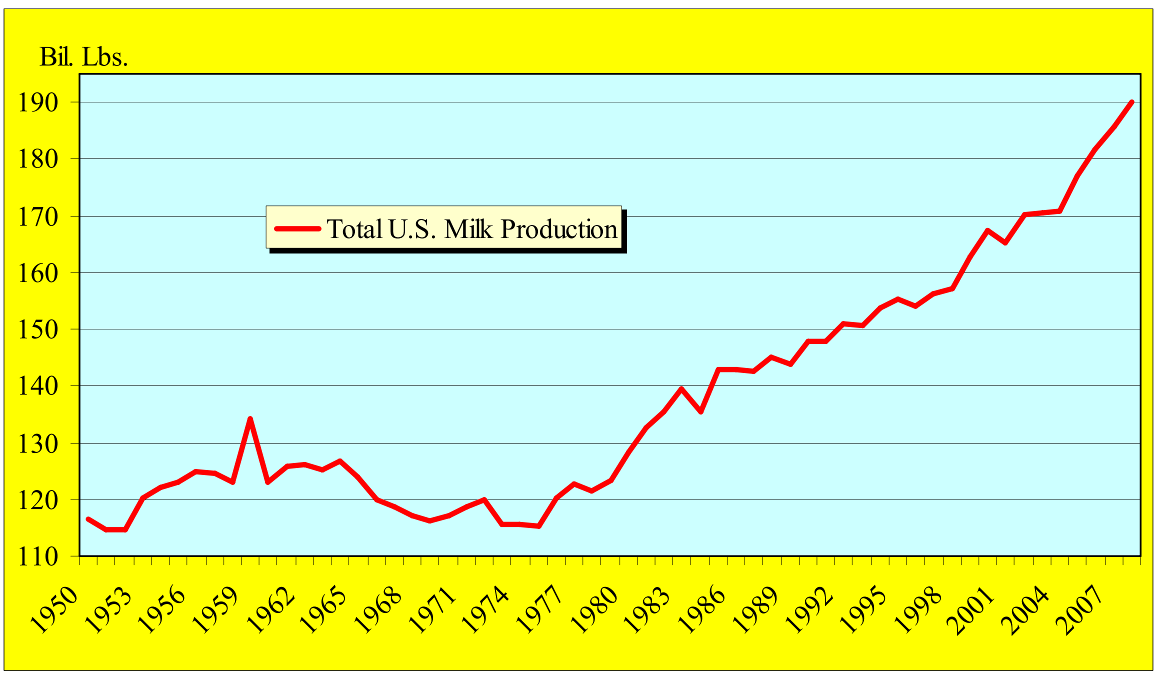


Figure 2. U.S. Dairy Herd, Per Cow Productivity, and Total U.S. Milk Production 1950-2008.

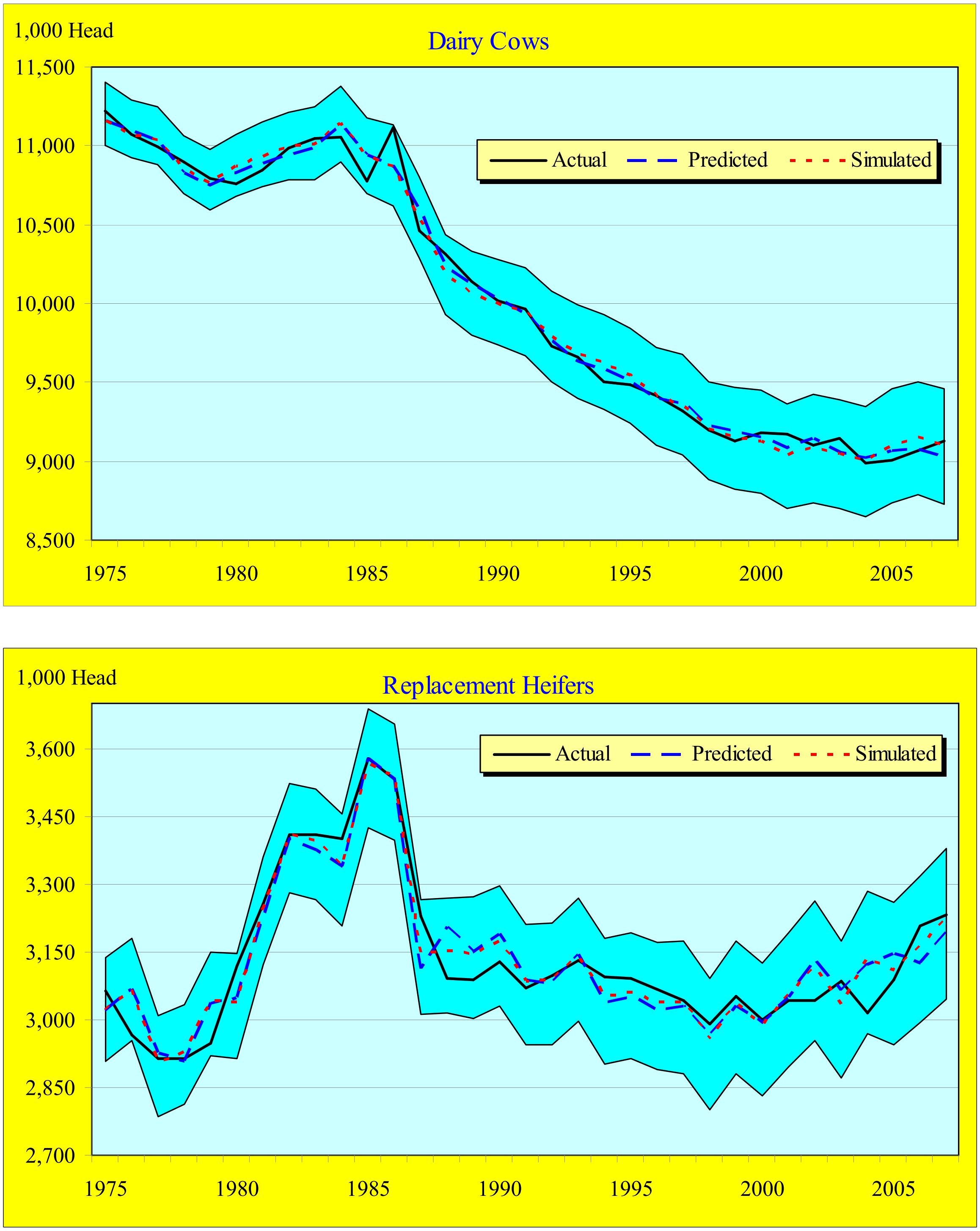


Figure 3. Comparison of Actual and Predicted Number of Dairy Cows and Replacement Heifers

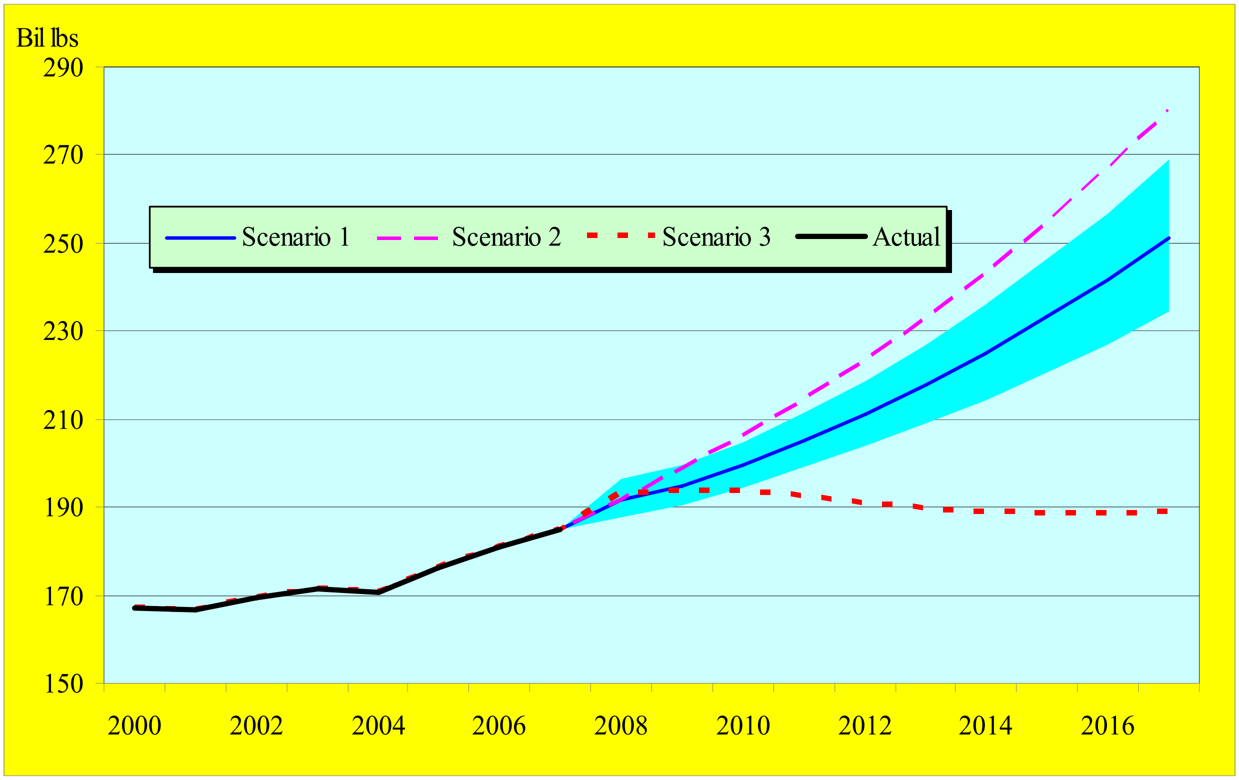


Figure 4. Impact of Alternative Price Scenarios on Future U.S. Milk Production

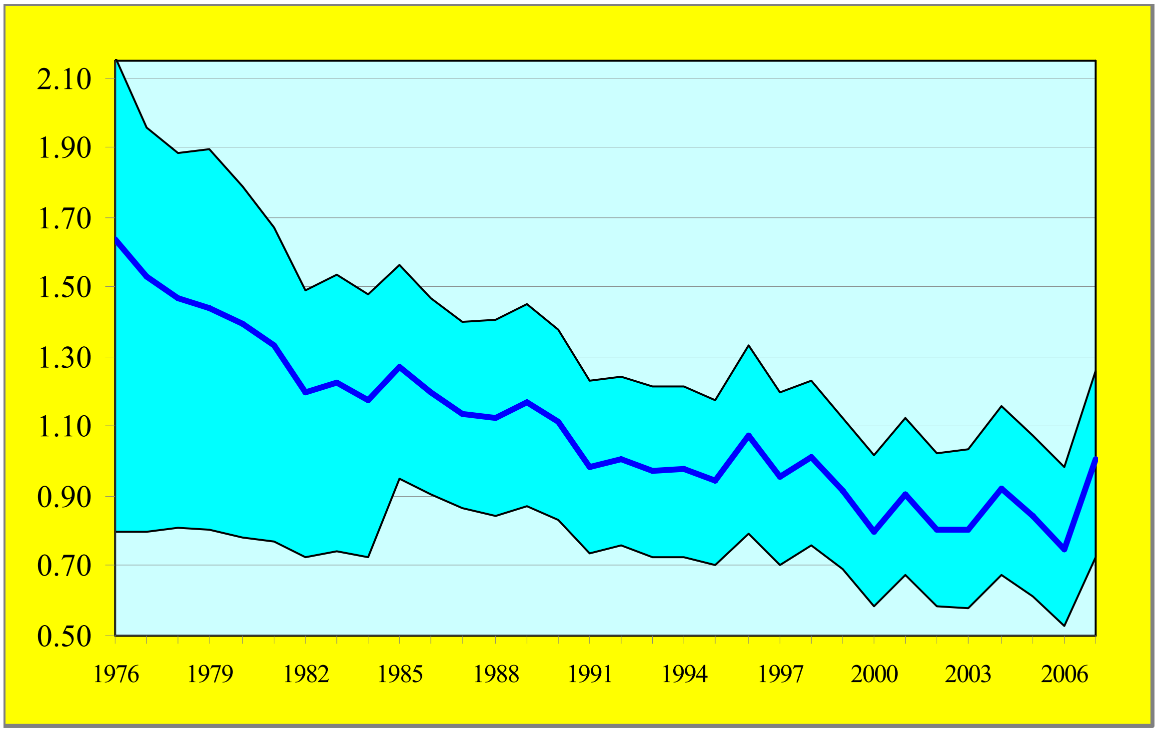


Figure 5. Estimated Herd Size Elasticity and Associated Confidence Interval.

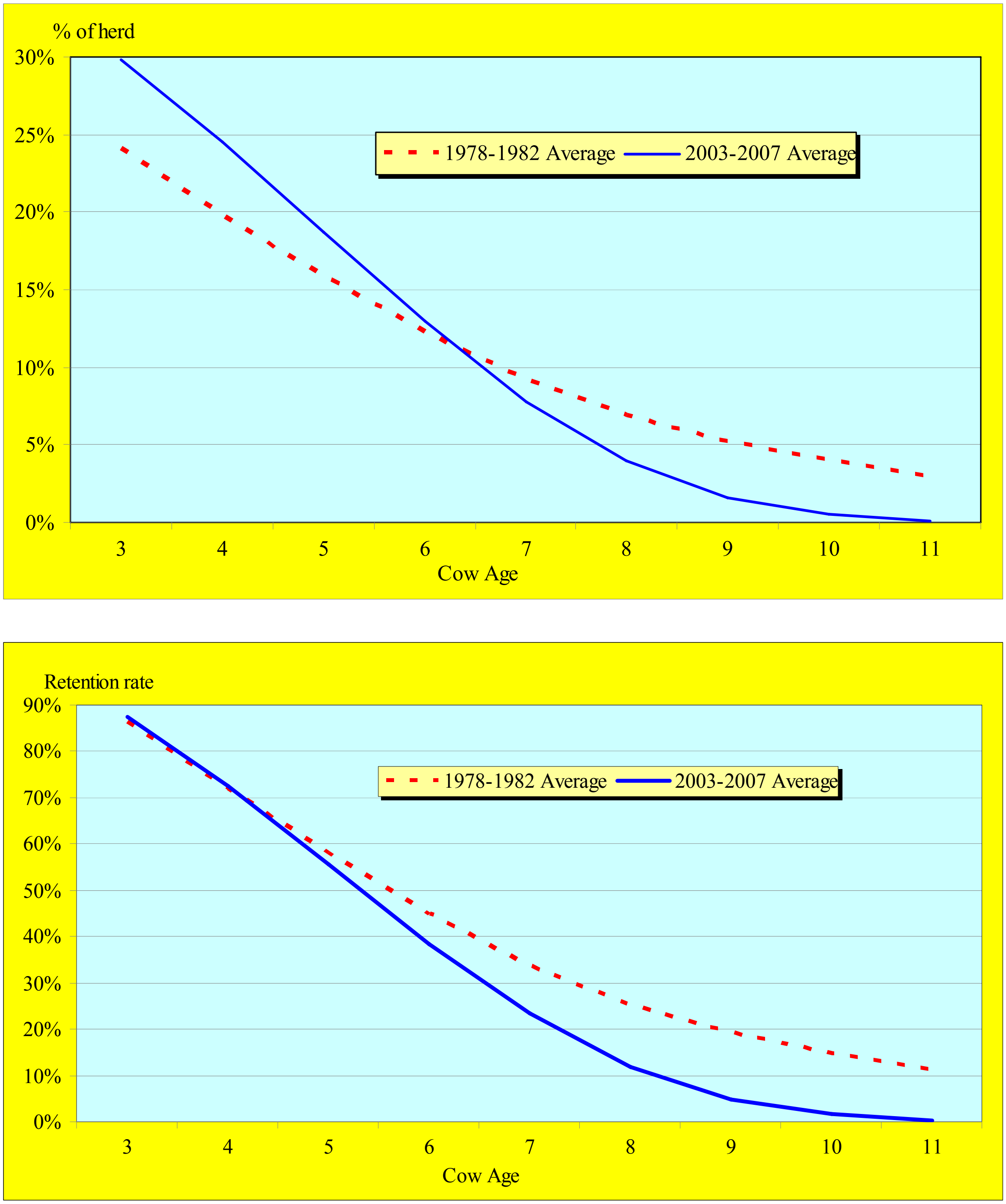


Figure 6. Herd Structure and Herd Retention Rates by Cow Age

Table 1. Distribution of Milk Production by Herd Size, Selected Years

Year	Number of Dairy Farms	Average Herd Size	Percent of U.S. Milk Production							
			<100	100-199	200+	200-499	500+	500-999	1000-1999	2000+
1994	148,140	64.1	41.4	19.2	39.4	-----	-----	-----	-----	-----
1996	130,980	71.6	37.7	20.0	42.3	-----	-----	-----	-----	-----
1998	117,145	78.1	33.8	19.0	47.2	16.7	30.5	11.2	10.9	8.4
2000	105,055	87.6	28.9	17.2	53.9	18.0	35.9	13.8	11.6	10.5
2002	91,240	100.2	24.7	15.2	60.1	16.8	43.3	13.9	13.8	15.6
2004	81,520	110.5	22.5	14.2	63.3	16.3	47.0	14.0	13.1	19.9
2006	74,980	121.5	20.3	13.0	66.7	15.2	51.5	13.4	14.6	23.5
2008	67,000	139.0	16.6	11.8	71.6	13.1	58.5	12.5	15.5	30.5

Source: NASS, QuickStats

Table 2. Listing of Explanatory Variables by Category

Dependent Variable	Explanatory variables				
	Symbol	Category			
		Technology, Herd Structure	Prices		Government Policy
COW_t	$Z_{t-j,i-j}$ $i=1,..,9$ $\forall\, i,j=1,...,i$	$AGE = 1 - j + 3$	MP_{t-j}	MP_{t-j} x AGE	$Dum84 = \begin{cases} 1, & \text{if } t-i+j=1985 \\ 0, & \text{otherwise} \end{cases}$
			FP_{t-j}	FP_{t-j} x AGE	
		$\frac{HEF_{t-j}}{COW_{t-j}}(AGE-3)$	SP_{t-j}	SP_{t-j} x AGE	$Dum86 = \begin{cases} 1, & \text{if } t-i+j=1987/1988 \\ 0, & \text{otherwise} \end{cases}$
HEF_t	W_t	$T = t - 1974$	MP_{t-1}	MP_{t-3}	$Dum84 = \begin{cases} 1, & \text{if } t=1985 \text{ or } 1986 \\ 0, & \text{otherwise} \end{cases}$
			FP_{t-1}	FP_{t-3}	
			FP_{t-1}	SP_{t-3}	$Dum86 = \begin{cases} 1, & \text{if } t=1987 \text{ or } 1988 \\ 0, & \text{otherwise} \end{cases}$
YLD_t	X_t	$T = t - 1974$	MP_t	MP_{t-1}	$Dum84 = \begin{cases} 1, & \text{if } t=1984 \\ 0, & \text{otherwise} \end{cases}$
		YLD_{t-1}	FP_t	FP_{t-1}	

Table 3. Descriptive Statistics for Model Variables

Variable	Units	Description	Mean	St. Dev.	Min.	Max.
COW	1,000 Head	Dairy cows, USDA Cattle inventory, January 1	10,552	1322	8,990	14,452
HEF	1,000 Head	Replacement heifers, 75% of published cattle inventory data for January 1 "500+ lbs heifers"	3,066	203	3,442	4,770
YLD	lbs/year	Yield per cow	15002	2,999	10,293	20,267
FC	\$2007/cwt	Feed cost, 16% protein dairy feed	24.58	7.04	13.25	35.21
MP	\$2007/cwt	All milk price. MILC payment added for 2001-2008	9.23	3.55	4.87	19.33
SP	\$2007/cwt	Omaha/Sioux Falls boning utility cow slaughter price	81.91	29.27	40.08	153.62
AGE_{ij}	#	Age of i-th productive age class at j-th culling period	--	--	3	11
Dum84	0/1	Dummy variable for Milk Diversion Program, active in 1984	0.03	--	--	--
Dum86	0/1	Dummy variable for Whole-Herd Buy-Out Program, active in 1986-87	0.06	--	--	--
PROD	Mil lbs	Total U.S. Milk production, calculated as identity: PROD=COW x YIELD	149,516	17,929	116,235	185,078

Table 4. Estimated Model of U.S. Dairy Supply (1975-2007)

(10.1)
$$HEF_t = \frac{1}{2} COW_{t-2} \Big/ \left[1 + \exp\left(\underset{(0.150)}{0.758} - \underset{(0.003)}{0.019}\, T - \underset{(0.030)}{0.136}\, Dum84 + \underset{(0.003)}{0.126}\, Dum86 - \underset{(0.006)}{0.016}\, MP_{t-1} + \right.\right.$$
$$\left.\left. + \underset{(0.008)}{0.022}\, FP_{t-1} + \underset{(0.001)}{0.003}\, SP_{t-1} - \underset{(0.005)}{0.011}\, MP_{t-2} + \underset{(0.008)}{0.014}\, FP_{t-2} - \underset{(0.001)}{0.003}\, SP_{t-2} \right)\right] \qquad R^2 = 0.883$$

(10.2)
$$COW_t = \sum_{i=1}^{9} H_{t-i} \Big/ \left\{ \prod_{j=1}^{i} \left[1 + \exp\left(-\underset{(0.789)}{2.694} + \underset{(0.079)}{0.151}\, Dum84 + \underset{(0.031)}{0.231}\, Dum86 - \underset{(0.057)}{0.063}\, MP_{t-j} \right.\right.\right.$$
$$+ \underset{(0.087)}{0.249}\, FP_{t-j} + \underset{(0.007)}{0.002}\, SP_{t-j} - \underset{(0.167)}{0.213}\, AGE + \underset{(0.010)}{0.008}\, MP_{t-j} \cdot AGE$$
$$\left.\left.\left. - \underset{(0.016)}{0.044}\, FP_{t-j} \cdot AGE - \underset{(0.001)}{0.001}\, SP_{t-j} \cdot AGE + \underset{(0.316)}{0.980} \frac{HEF_{t-j}}{COW_{t-j}} \left(AGE - 3 \right) \right)\right]\right\} \qquad R^2 = 0.991$$

(10.3)
$$YLD_t = \underset{(1381.36)}{5093.17} + \underset{(50.77)}{204.89}\, T - \underset{(142.29)}{463.26}\, Dum84 - \underset{(15.16)}{17.75}\, MP_t + \underset{(34.35)}{28.29}\, FP_t + \underset{(15.23)}{38.08}\, MP_{t-1}$$
$$- \underset{(26.48)}{8.04}\, FP_{t-1} + \underset{(0.15)}{0.40}\, YLD_{t-1} \qquad R^2 = 0.998$$

(10.4)
$$PROD_t = YLD_t \times COW$$

Note: Asymptotic standard errors are in parenthesis. The variables are defined as follows:

HEF_t = the number of replacement heifers intended to enter the herd in the current year and calculated as 75% of heifers over 500lbs. on dairy farms on 1 Jan. (1,000 head)
COW_t = the annual average number of dairy cows on dairy farms (1,000 head)
MP_t = U.S. All-Milk price plus MILC payments ($/cwt)
FC_t = the value of a 16% protein dairy ration (51% corn, 41% hay, 8% soybeans) ($/cwt)
SP_t = Omaha/Sioux Falls slaughter cow bonning/utility price ($/cwt)
T = time trend (1=1975; 2=1976; etc.)
AGE = (i – j + 3) where i = 1,…,9 j = 1,…,9
$DUM84_t$ = a dichotomous dummy variable identifying the Milk Diversion Program active in 1984.
$DUM86_t$ = a dichotomous dummy variable identifying the Whole-herd Buy-out Program active in 1986-87
YLD_t = production per cow (lbs)
$PROD_t$ = U.S. milk production (billion lbs).

Table 5. Predicted Marginal Impact of Prices on Cow Culling: 2007

Age (i + 2)	Cull rate (k_{ti})	Marginal Price Impact					
		$\Delta k_{ti} / \Delta MP_{2007}$		$\Delta k_{ti} / \Delta FP_{2007}$		$\Delta k_{ti} / \Delta SP_{2007}$	
3	12.6%	-0.8%	(0.5%)	0.9%	(0.3%)	0.0%	(0.2%)
4	17.3%	-0.9%	(0.4%)	0.7%	(0.2%)	0.0%	(0.1%)
5	23.4%	-0.8%	(0.2%)	0.4%	(0.2%)	0,0%	(0.1%)
6	30.7%	-0.5%	(0.4%)	-0.2%	(0.2%)	-0.1%	(0.1%)
7	39.2%	-0.2%	(0.9%)	-0.9%	(0.4%)	-0.2%	(0.3%)
8	48.4%	0.3%	(1.5%)	-1.7%	(0.7%)	-0.3%	(0.5%)
9	57.7%	0.7%	(2.0%)	-2.4%	(0.9%)	-0.3%	(0.6%)
10	66.5%	1.0%	(2.3%)	-2.9%	(1.2%)	-0.4%	(0.7%)
11	74.2%	1.2%	(2.4%)	-3.1%	(1.3%)	-0.4%	(0.8%)

Note: These are the effect of a 10% increase over the 2007 level

Table 6. Short Run and Intermediate Run Elasticities of U.S. Dairy Supply to Milk and Feed Price Changes

	Years Since Price Change (j)														
1978-1982	1			3			6			10			25		
	Elas.	Low	High	Elas.	Low	High	Elas.	Low	High	Elas.	Low	High	Elas.	Low	High
Elasticity of															
HEF_t w.r.t. MP_{t-j}	0.277	0.105	0.449	0.551	0.337	0.718	0.949	0.628	1.205	1.573	1.062	1.979	3.950	2.609	5.050
COW_t w.r.t. MP_{t-j}	0.051	-0.102	0.091	0.293	0.104	0.378	0.737	0.453	0.909	1.361	0.867	1.697	3.749	2.406	4.797
$PROD_t$ w.r.t. MP_{t-j}	0.086	-0.070	0.190	0.374	0.165	0.496	0.823	0.527	1.016	1.443	0.940	1.792	3.823	2.481	4.877
Elasticity of															
HEF_t w.r.t. FP_{t-j}	-0.139	-0.227	-0.051	-0.251	-0.326	-0.122	-0.422	-0.559	-0.180	-0.729	-0.977	-0.295	-1.630	-2.182	-0.606
COW_t w.r.t. FP_{t-j}	-0.004	-0.047	0.123	-0.113	-0.209	0.086	-0.350	-0.524	-0.021	-0.649	-0.934	-0.122	-1.582	-2.174	-0.466
$PROD_t$ w.r.t. FP_{t-j}	0.026	-0.037	0.164	-0.083	-0.189	0.125	-0.323	-0.504	0.010	-0.626	-0.914	-0.093	-1.566	-2.159	-0.445
2003-2007	1			3			6			10			25		
	Elas.	Low	High	Elas.	Low	High	Elas.	Low	High	Elas.	Low	High	Elas.	Low	High
Elasticity of															
HEF_t w.r.t. MP_{t-j}	0.123	0.047	0.198	0.282	0.197	0.357	0.526	0.394	0.648	0.869	0.651	1.071	2.207	1.593	2.819
COW_t w.r.t. MP_{t-j}	0.066	0.027	0.091	0.226	0.155	0.286	0.488	0.357	0.610	0.835	0.611	1.046	2.204	1.568	2.848
$PROD_t$ w.r.t. MP_{t-j}	0.076	0.031	0.116	0.251	0.171	0.315	0.514	0.375	0.638	0.861	0.631	1.075	2.228	1.586	2.876
Elasticity of															
HEF_t w.r.t. FP_{t-j}	-0.061	-0.100	-0.022	-0.122	-0.156	-0.077	-0.232	-0.293	-0.138	-0.390	-0.494	-0.217	-0.960	-1.234	-0.480
COW_t w.r.t. FP_{t-j}	-0.012	-0.028	0.023	-0.088	-0.131	-0.014	-0.219	-0.298	-0.083	-0.379	-0.503	-0.161	-0.968	-1.267	-0.438
$PROD_t$ w.r.t. FP_{t-j}	-0.003	-0.025	0.037	-0.079	-0.126	-0.001	-0.210	-0.290	-0.070	-0.371	-0.496	-0.151	-0.962	-1.262	-0.429

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